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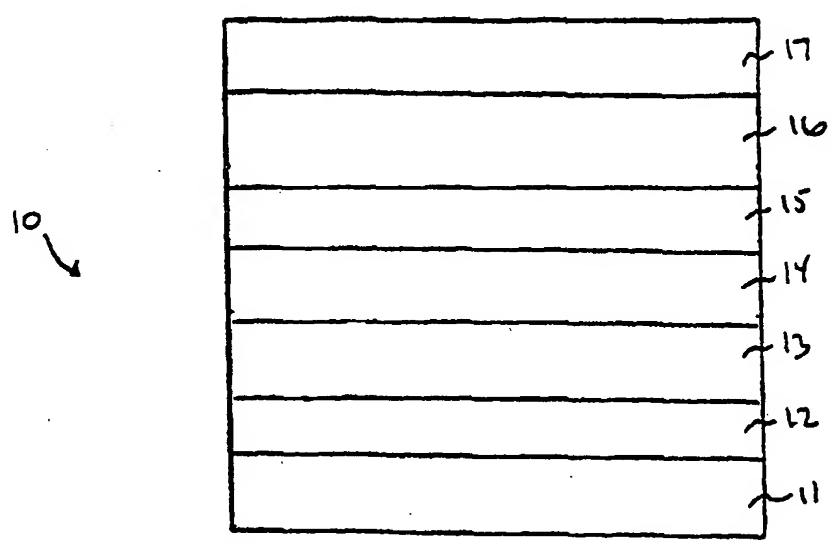
(57) Abstract

An organic light emitting device (10) having a doped organic layer (16) with increased thickness and conductivity. The doped organic layer permits the formation of reliable and large area displays.



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ACTIVE MATRIX ORGANIC LIGHT EMITTING DIODE WITH DOPED ORGANIC LAYER HAVING INCREASED THICKNESS

Cross Reference To Related Patent Application

This application relates to and claims priority on U.S. Provisional Application Serial No. 60/101,683, filed September 24, 1998.

Field of the Invention

The present invention relates to an organic light emitting device (OLED). In particular, the present invention relates to an OLED display device having a doped organic layer with increased thickness and conductivity.

Background of the Invention

OLED displays typically include multiple layers of organic compounds which are insulating or high band gap pure semiconductors. These organic layers have high resistance. The individual organic layers are typically very thin ($< 0.1\mu m$) and the total organic layer stack thickness is typically less than $0.2\mu m$ in order to keep the drive voltage low and the power efficiency high. The use of the extremely thin layers, however, makes the OLEDs more susceptible to shorting and other defects. Furthermore, manufacturing with high uniformity and yield is more difficult.

The prior art contains OLED's having a wide range of organic layer thickness. The key point of the present invention is to dope at least one or part of one organic layer to increase its conductivity to be able to increase the thickness of the layer without a significant increase in the OLED drive voltage.

Objects of the Invention

It is an object of the present invention to provide an organic light emitting device having an organic layer with increased thickness.

It is another object of the present invention to provide an organic light emitting device having an organic layer with increased thickness providing increased reliability.

It is another object of the present invention to provide an organic light emitting device having an organic layer with increased thickness which permits the manufacturing of displays with increased area.

It is another object of the present invention to provide an organic light emitting device having an organic layer with increased thickness which permits the manufacturing of displays on imperfect substrates.

It is another object of the present invention to provide an organic light emitting device with low drive voltage having a doped organic layer with increased thickness.

It is another object of the present invention to provide an organic light emitting device with high power efficiency having a doped organic layer with increased thickness.

It is another object of the present invention to produce an organic light emitting device display with improved manufacturing reliability and yield.

Furthermore, it is another object of the present invention to provide an organic light emitting device having reduced requirements on substrates.

It is another object of the present invention to provide a multilayer conductive organic layer to keep the emission zone in the OLED highly luminescent.

It is another object of the present invention conductive organic layer having a gradual doping design to keep the emission zone in the OLED highly luminescent.

Summary of the Invention

The present invention is directed to an improved organic light emitting device display device. The device includes a substrate, a first conductor, at least one organic layer and a second conductor. According to the present invention, at least one of the organic layers is a doped organic layer to increase its electrical conductivity. The doped organic layer includes a concentration of dopant. The concentration of dopant of the doped organic layer may be uniform throughout the layer.

It is also contemplated and preferred that the concentration of the dopant may increase. The concentration of dopant increases adjacent the second conductor. There may be uniform increase in concentration. Alternatively, there may be a stepwise increase in concentration.

The organic light emitting device according to the present invention may also include an undoped organic layer. The doped organic layer may have a thickness greater that the thickness of the undoped organic layer. Furthermore, the concentration of dopant in the doped organic layer may be uniform. Likewise, the concentration of dopant in the doped organic layer may increase from the undoped organic layer to the second conductor.

Brief Description of the Drawings

The invention will now be described in conjunction with the following drawings in which like reference numerals designate like elements and wherein:

Fig. 1 illustrates an organic light emitting device according to an embodiment of the present invention; and

Fig. 2 illustrates another organic light emitting device according to another embodiment of the present invention.

Detailed Description of Preferred Embodiments

The present invention is directed to an OLED **10**, shown in Fig. 1. The OLED **10** includes a substrate and a first electrode layer **11**. The first electrode may be formed on the substrate. The first electrode may be an anode. The substrate is preferably a CMOS silicon substrate. Other suitable substrates including but not limited to glass, quartz, plastic and silicon, however, are considered to be well within the realm of the present invention. The substrate is preferably an active matrix Si chip. The active matrix Si chip includes drive electronics formed thereon and patterned pixel electrodes. The OLED **10** has one common electrode. The OLED may be up-emitting or down-emitting active matrix OLED on glass, quartz, plastic or silicon. The active matrix OLED may be formed using amorphous, poly-

crystalline or single-crystalline silicon active matric circuitry. Non-silicon technology may also be used.

A stack of organic layers **12-17** is formed on the substrate electrode layer **11**. An injector layer **12** is formed on the substrate electrode layer **11**. The injector layer **12** is preferably formed from CuPc (copper pthalocyanine). It, however, is contemplated by the inventor of the present invention that other suitable materials having similar properties may be used to form layer **12**. A hole transporter layer **13** is formed on the injector layer **12**. The hole transporter layer **13** is preferably formed from NPB (4,4^1-bis[N-(1-naphthyl)-N-phenyl-amino]-biphenyl). It, however, is contemplated that other suitable materials may be used to form the hole transporter layer **13**.

An emitter doped Alq_3 layer **14** is formed on top of the hole transporter layer **13**. A thin undoped Alq_3 layer **15** is formed on the emitter doped Alq_3 layer **14**. A doped Alq_3 layer **16** that is more conductive is formed on the layer **15**. It is preferred that the doping in layer **16** gradually increase such that the greatest concentration of dopant is located adjacent an electrode layer **17**. The conductivity of the layer **16** increases as the dopant concentration increases. The layer **16** may be formed from an n-type doped Alq_3. The layer **16** may be formed by co-evaporation. Finally, the electrode **17** is positioned above the layer **16**. In a preferred embodiment, the electrode **17** is a cathode. Furthermore, it is preferred that the electrode **17** is formed from a transparent material or a material that permits the transmission of light therethrough.

The doped layer may have a thickness greater than the thickness of the other organic layers. A thickness, however, less than the thickness of the other organic layers is also contemplated. A typical OLED (without the doped organic layer of the invention) may have a total organic layer thickness of x to give optimized light output, low voltage, high power efficiency, etc. With the present invention, the total organic layer thickness will be larger than x but with possible improvements on light output, low voltage, high power efficiency. However, the doped organic layer of the present invention may have a very wide range of thicknesses (absolute and relative) to the total organic layer thickness x. The total thickness of the organic layer thickness increase by at least 10% but preferably 30% and better still

50% compared to the "undoped case" but the total OLED drive voltage of the doped case would not be more than 10% larger than that of the undoped case.

Another embodiment of the present invention is shown in Fig. 2. An organic light emitting device **20** includes a substrate and electrode layer **21**. The layer **21** is similar to the layer **11**, described above. An injector layer **22** is formed on the substrate electrode layer **21**. A hole transporter layer **23** is formed on the layer **22**. An emitter doped Alq_3 layer **24** is formed on top of the hole transporter layer **23**. A second doped Alq_3 layer **25** is formed on the doped Alq_3 layer **24**. The layer **25** may uniformly doped. It is preferred, however, that the doping in layer **25** gradually increase such that the greatest concentration of dopant is located adjacent the common cathode **26**, which is formed on top of the layer **25**.

The composition of doped layers **16** and **25** will now be described in accordance with embodiments of the present invention. In accordance with the present invention, the thickness of at least one of the organic layers (e.g., layers **16** and **25**) in the OLED **10** and **20** is made thicker when compared to the prior art. The consideration of such thicker layers without strongly increasing the overall OLED drive voltage is permitted and accomplished by doping the organic layer to increase its electrical conductivity. Furthermore, the use of a thicker organic layers **16** and **25** improves the reliability of manufacture of larger area displays. The displays are also more reliable and less sensitive to defects and unevenness on the substrate. The displays exhibit low drive voltage and high power efficiency.

It is contemplated that the present invention may be used with active matrix-driven OLEDs having one of the two electrodes as a common electrode. The common electrode may be either the anode or the cathode of the OLED. Under the common electrode, the organic layers can be doped according to the present invention to make it more conductive. Conductive organic layers tend to show significantly reduced photo luminescents efficiency. The present invention, however, uses a multi-layer and/or gradual doping design to keep the emission zone highly (electro/photo) luminescent.

As discussed above, the active matrix OLEDs **10** and **20** may have one common electrode. The doped layer is preferably adjacent the common electrode. The active matrix OLED preferably has pixelated anode bottom electrodes and a transparent or semi-transparent

top common electrode. In this case, the doped layer is a doped electron injection transporting layer.

In accordance with the present invention, it is important to carefully chose and balance the doping profile, the dopants, the balance of electron and hole current, the various layer thicknesses as well as the emitter-dopant to trap electrons and holes for excitons in order not to spatially overlap the electrically doped zone with the emitter doped zone to assure that photo-luminescence and electro-luminescence efficiency remain high. It is anticipated that the preferred thickness for the doped organic layer(s) of the invention is in the range of 50 to 500 nm. It, however, is contemplated that other-thicknesses are within the scope of the present invention. The optimum thickness depends on the requirements for making the OLED more "robust" by increasing the organic layer thickness, the achievably conductivity range for the doped organic layer, is conductivity-transparency relationship, interference and/or output-coupling effects, etc.

For example, a typical yellow-green emitting state-of-the-art OLED takes about 5 mA/cm^3 at voltages between 5 and 10 V to achieve a light output of several hundred CD/m^2. If the doped organic layer has a thickness of 200 nm, the organic doped layer needs to have a minimum conductivity of about $2x10^{-7}$ S/cm to assure that the additional voltage drop across the doped organic layer stays below 0.5 V. Therefore, taking thicknesses of the doped organic layer between 50 and 500 nm and a maximum allowed additional voltage increase of 0.5 V into account, the organic layer needs to have values in the 10^{-7} and 10^{-8} S/cm conductivity decades/range. This can easily be achieved with low levels of doping.

If doping to values of 10^{-8} to 10^{-7} S/cm results in unacceptable high levels of absorption of the doped organic layer of the light from the OLED, then the doping concentration and doped layer thickness can be reduced. In a preferred form, the doping profile of the doped organic layer is not uniform but changes from low doping (conductivity) closer to the emissive zone of the OLED to higher doping (conductivities) closer to the top electrode and thus the conductivity of the doped organic layer may have a profile ranging from 10^{-5} S/cm close to the top electrode to less than 10^{-10} S/cm close to the emissive zone. The change in concentration may be uniform. It, however, is contemplated that a nonuniform

(i.e., stepwise) change in concentration of dopant is well within the scope of the present invention.

Various materials may be used to dope the organic layers **16** and **25**. For example, the following materials are considered to be suitable dopants: TTF-TCNQ (an organic charge transfer crystal – in which one molecule is an acceptor and another molecule is a donor; the acceptor may be used as acceptor dopant in a hole0ijnecting and/or hole-transporting doped layer of the present invention or the donor part may be used as the donor dopant in an electron-injecting and/or electron-transporting doped layer of the present invention); DDQ; and various other n-type dopants that have suitable mobility and molecule sublimation properties, as well as, suitable thermal and current/voltage stress stability. Generally, if a hole (electron) transporting/injecting layer is used as the doped layer of the invention then the dopant needs to have the ability to increase the conductivity of the host layer by way of example, a charge transfer reaction in which the dopant accepts charge carriers from the host (donates charge carriers to the host) to increase the hole (electron) current in the layer. Furthermore, inorganic materials, such as metals, re potential dopants in the doped layer. Alkali and earth-alkaline metals are potential dopants fort the electron transporting/injecting layer of the present invention under the cathode.

While this invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. For example, in an OLED having a common anode, the hole transport layer **13** and **23** may be doped to make the layer thicker. In many applications, the top emitting electrode should have the highest possible transparency. Therefore the electrically-doped organic layer must also be transparent, or at least as much as possible. Therefore, the doping of the organic layer must be such that the doped organic layer stays predominantly transparent. It is possible to slightly dope organic layers, whereby the conductivity increases substantially but by retaining most of its transmission. A key point in this respect is also that the doped organic layer of the present invention does not have to be highly conductive to keep the drive voltage low. Accordingly, the preferred embodiments of the invention as set forth herein are intended to be illustrative, not limiting. The present invention is particularly

applicable to OLEDs that have one of the two electrodes as a common electrode such as active-matrix OLEDS. The inventio, however, may also be used in low and high resolution segmented and passive-matrix displays provided that action is taken to reduce or avoid lateral current spending/leakage between the electrode elements adjacent to the doped layer of the invention. One possible way to do this is to pattern the layer of the present invention to render portions of it less conductive. Another way would be to use spacer structures to separate the top electrode elements such as described, for example, in Hosakara et al., SID Digest 1998, Vol. XXIX.

What is claimed is:

1. In an organic light emitting display device having a substrate, a first conductor, at least one organic layer and a second conductor, the improvement comprising:

at least one of said at least one organic layer is a doped organic layer to increase the conductivity of said layer.

2. The organic light emitting display device according to Claim 1, wherein said doped organic layer has a thickness and includes a concentration of dopant, whereby said concentration of dopant in said doped organic layer is uniform across said thickness.

3. The organic light emitting display device according to Claim 1, wherein said doped organic layer is located adjacent said second conductor, said doped organic layer includes a concentration of dopant, whereby said concentration of dopant in said doped organic layer increases adjacent said second conductor.

4. The organic light emitting display device according to Claim 3, wherein said increase in concentration is uniform.

5. The organic light emitting display device according to Claim 3, wherein said increase in concentration is stepwise.

6. The organic light emitting display device according to Claim 1, wherein said at least one organic layer includes said doped organic layer and an undoped organic layer.

7. The organic light emitting display device according to Claim 6, wherein said doped organic layer has a thickness greater that the thickness of said undoped organic layer.

8. The organic light emitting display device according to Claim 7, wherein said doped organic layer includes a concentration of dopant, whereby said concentration of dopant in said doped organic layer is uniform across said thickness of said doped organic layer.

9. The organic light emitting display according to Claim 7, wherein said doped organic layer includes a concentration of dopant, whereby said concentration of dopant in said doped organic layer increases across said thickness of doped organic layer.

10. The organic light emitting display device according to Claim 6, wherein said doped organic layer is located between said second conductor and said undoped organic layer, said doped organic layer includes a concentration of dopant, whereby said

concentration of dopant in said doped organic layer uniformly increases from said undoped organic layer to said second conductor.

11. The organic light emitting display device according to Claim 6, wherein said doped organic layer is located between said second conductor and said undoped organic layer, said doped organic layer includes a concentration of dopant, whereby said concentration of dopant in said doped organic layer stepwise increases from said undoped organic layer to said second conductor.

12. The organic light emitting display device according to Claim 1, wherein said organic light emitting display device is an active matrix organic light emitting device.

13. The organic light emitting display device according to Claim 1, wherein said organic light emitting display device includes top and bottom electrodes.

14. The organic light emitting display device according to Claim 13, wherein one of said top and bottom electrodes is a common electrode.

15. The organic light emitting display device according to Claim 14, wherein said doped organic light emitting display device is an organic light emitting device.

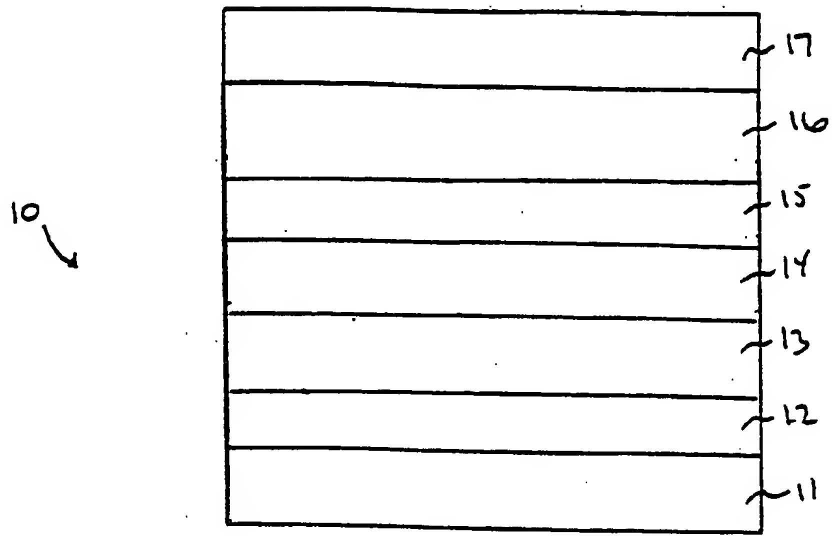

FIG. 1

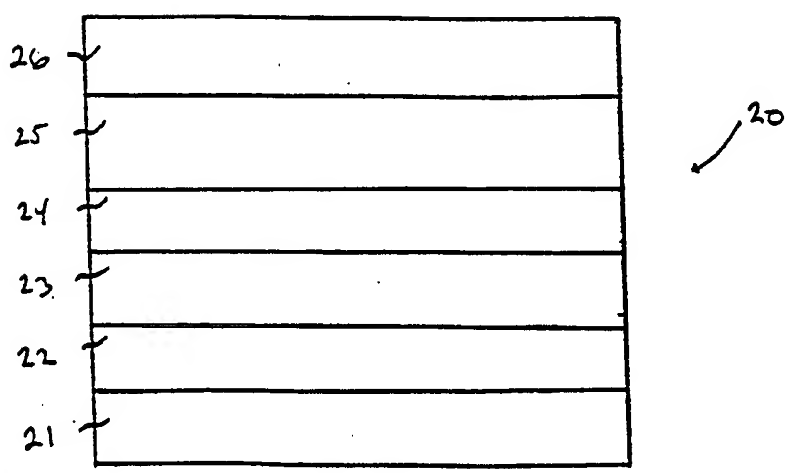

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01 J 63/04
US CL :313/506
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 313/498, 506

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,559,400 A (NAKAYAMA et al) 24 September 1996, (24/09/96) Fig.1.	1, 2-8, and 12-15.
X/A	US 5,247,226 A (SATO et al) 21 September 1993 (21-09-93), Figure 1.	1-2, 6-8, and 12-15/3, 9-11

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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